

WHAT IS CLAIMED IS:

1. In a digital communication system, a method for communicating comprising the steps of:

- transmitting signals from one or more transmitter antenna elements;
- receiving said signals from via a plurality of receiver antenna elements;
- wherein separation of radiation patterns among either said transmitter antenna elements or said receiver antenna elements is insufficient to establish completely isolated spatial directions for communication; and wherein
- at least one of said transmitting and receiving steps comprises processing said signals to increase isolation between spatial directions employed for communication at a common frequency.

2. The method of claim 1 wherein a channel coupling said plurality of transmitter antenna elements and receiver antenna elements at said common frequency is characterized by a spatial channel matrix having a rank greater than one.

3. In a digital communication system, a method for communicating comprising the steps of:

- transmitting signals from one or more transmitter antenna elements;
- receiving said signals via a plurality of receiver antenna elements;
- wherein separation of radiation patterns among either said transmitter antenna elements or said receiver antenna elements is insufficient to establish completely isolated spatial directions for communication; and wherein
- at least one of said transmitting and receiving steps comprises processing said signals to increase isolation between subchannels, each subchannel associated with a spatial direction and a bin of a substantially orthogonalizing procedure.

4. The method of claim 3 wherein said substantially orthogonalizing procedure belongs to a group including: an inverse Fast Fourier Transform, a Fast Fourier Transform, a Hilbert transform, a wavelet transform, and processing through a set of bandpass filter/frequency upconverter pairs operating at spaced apart frequencies..

32
33 5. In a digital communication system, a method for preparing a sequence of
34 symbols for transmission via a plurality of inputs of a channel:

35 a) inputting said symbols of said sequence into a plurality of inputs
36 corresponding to a plurality of subchannels of said channel, each subchannel corresponding to
37 an input bin of a transmitter substantially orthogonalizing procedure and a spatial direction;

38 b) for each input bin, spatially processing symbols inputted to said subchannels
39 corresponding to said input bin, to develop a spatially processed symbol to assign to each
40 combination of channel input and input bin of said transmitter substantially orthogonalizing
41 procedure; and

42 c) applying, independently for each said channel input, said transmitter
43 substantially orthogonalizing procedure to said spatially processed symbols assigned to each
44 said channel input.
45

46 6. The method of claim 5 wherein said b) step has the effect of making
47 spatial directions of said subchannels into a set of orthogonal spatial dimensions.
48

49 7. The method of claim 5 wherein said transmitter substantially
50 orthogonalizing procedure belongs to one of a group consisting of an inverse Fast Fourier
51 Transform, a Fast Fourier Transform, a discrete cosine transform, a Hilbert transform, a
52 wavelet transform, and processing through a plurality of bandpass filter/frequency converter
53 pairs centered at spaced apart frequencies.
54

55 8. The method of claim 5 further comprising the step of, after said c) step,
56 applying a cyclic prefix processing procedure to a result of said substantially orthogonalizing
57 procedure independently for each channel input.
58

59 9. The method of claim 5 wherein said transmitter substantially
60 orthogonalizing procedure is optimized to reduce interference to unintended receivers.
61

62 10. The method of claim 5 wherein said b) step comprises, for each
63 particular input bin, multiplying a vector comprising symbols allocated to subchannels
64 corresponding to said input bin by a beneficial weighting matrix, elements of a result vector of
65 said multiplying step corresponding to different channel inputs of said plurality of channel
66 inputs.

67
68 11. The method of claim 10 wherein said beneficial weighting matrix
69 comprises an input singular matrix of a matrix containing values representing characteristics of
70 said channel, said coupling said plurality of channel inputs to one or more channel outputs.

71
72 12. The method of claim 10 wherein said beneficial weighting matrix is
73 obtained from a matrix containing values representing characteristics of a channel coupling
74 said plurality of channel inputs to one or more channel outputs.

75
76 13. The method of claim 10 wherein said beneficial weighting matrix is
77 chosen to reduce interference to unintended receivers.

78
79 14. The method of claim 13 wherein said beneficial weighting matrix is
80 chosen based upon characterization of a desired signal subspace.

81
82 15. The method of claim 14 wherein said beneficial weighting matrix is
83 chosen further based upon characterization of an undesired signal subspace.

84
85 16. The method of claim 15 wherein characterizations of said desired signal
86 subspace and said undesired signal subspace are averaged over at least one of time and
87 frequency.

88
89 17. The method of claim 10 wherein said b) step comprises performing said
90 spatial processing step so as to reduce interference radiated to unintended receivers.

91 18. The method of claim 10 wherein said b) step comprises, for each input
92 bin, allocating symbols to each combination of channel input and input bin so that there

is a one-to-one mapping between spatial direction of a particular subchannel to which a particular symbol has been allocated and channel input to which said particular symbol is allocated.

19. The method of claim 10 further comprising the step of prior to said b) step applying a coding procedure to said symbols.

20. The method of claim 19 wherein said coding procedure is applied independently for each of said subchannels.

21. The method of claim 19 wherein said coding procedure is applied independently for each group of subchannels corresponding to an input bin of said substantially orthogonalizing procedure.

22. The method of claim 19 wherein said coding procedure is applied independently for each group of subchannels corresponding to a particular spatial direction.

23. The method of claim 19 wherein said coding procedure is applied integrally across all of said subchannels.

24. The method of claim 19 wherein said coding procedure belongs to a group consisting of: convolutional coding, Reed-Solomon coding, CRC coding, block coding, trellis coding, turbo coding, and interleaving.

25. The method of claim 19 wherein said coding procedure comprises a trellis coding procedure.

26. The method of claim 25 wherein a code design of said trellis coding procedure is based on one of: improved bit error performance in interference channels, a periodic product distance metric, exhaustive code polynomial search for favorable bit error rate polynomial searches, combined weighting of product distance and Euclidean distance,

product distance of multiple Euclidean distances over short code segments or over a multi-dimensional symbol, and sum of product distances over short code segments.

27. The method of claim 25 wherein a code design of said trellis coding procedure is optimized for performance in a fading matrix channel.

28. The method of claim 19 wherein said coding procedure comprises a one-dimensional trellis coding procedure followed by an interleaving procedure with sequential groups of symbols output by said trellis coding having their internal order maintained by said interleaving procedure.

29. The method of claim 19 wherein said coding procedure comprises a multi-dimensional trellis coding procedure followed by an interleaving procedure with groups of one-dimensional symbols output simultaneously by said multi-dimensional trellis coding procedure having their internal order maintained by said interleaving procedure.

30. The method of claim 10 wherein bit loading and power are allocated to each subchannel.

31. The method of claim 10 further comprising the step of retransmitting symbols by repeating at least one of said a), b), and c) steps upon receipt of a notification that said symbols to be retransmitted have been incorrectly received.

32. The method of claim 10 wherein said channel comprises a wireless channel and said plurality of channel inputs are associated with a corresponding plurality of transmitter antenna elements

33. The method of claim 32 wherein said plurality of transmitter antenna elements are co-located.

154 34. The method of claim 32 wherein said plurality of transmitters are at
155 disparate locations.

156
157 35. A method of processing a sequence of symbols received via a plurality of
158 outputs of a channel, said method comprising the steps of:

159 a) applying a receiver substantially orthogonalizing procedure to said sequence
160 of symbols, said procedure being applied independently for each of said plurality of channel
161 outputs, each output symbol of said receiver substantially orthogonalizing procedure
162 corresponding to a particular output bin and a particular one of said channel outputs; and

163 b) for each output bin, spatially processing symbols corresponding to said
164 output bin to develop spatially processed symbols assigned to a plurality of spatial directions,
165 each combination of spatial direction and output bin specifying one of a plurality of
166 subchannels.

167
168 36. The method of claim 35 wherein said b) step has the effect of making
169 said plurality of spatial directions into a set of orthogonal spatial dimensions.

170
171 37. The method of claim 35 wherein said receiver substantially
172 orthogonalizing procedure belongs to one of a group consisting of an inverse Fast Fourier
173 Transform, a Fast Fourier Transform, a discrete cosine transform, a Hilbert transform, a
174 wavelet transform, and processing through a plurality of bandpass filter/frequency converter
175 pairs centered at spaced apart frequencies.

176
177 38. The method of claim 35 further comprising the step of, prior to said a)
178 step, applying a cyclic prefix removal procedure to said sequence of symbols independently
179 for each of said channel outputs.

180
181 39. The method of claim 35 wherein said receiver substantially
182 orthogonalizing procedure is optimized to reduce deleterious effects of interference from
183 undesired co-channel transmitters.

184

185 40. The method of claim 35 wherein said b) step comprises, for each
186 particular output bin, multiplying a vector comprising symbols of said output bin by a
187 beneficial weighting matrix, elements of a result vector of said multiplying step corresponding
188 to different spatial directions.

189
190 41. The method of claim 40 wherein said beneficial weighting matrix
191 comprises an output singular vector of a matrix containing values representing characteristics
192 of said channel, said channel coupling one or more channel inputs to said plurality of channel
193 outputs.

194
195 42. The method of claim 40 wherein said beneficial weighting matrix is
196 chosen to minimize deleterious effects of interference from undesired transmitters.

197
198 43. The method of claim 42 wherein said beneficial weighting matrix is
199 chosen based upon characterization of a desired signal subspace.

200
201 44. The method of claim 43 wherein said beneficial weighting matrix is
202 chosen further based upon characterization of an undesired signal subspace.

203
204 45. The method of claim 44 wherein said characterizations of said desired
205 signal subspace and said undesired signal subspace are averaged over at least one of time and
206 frequency.

207
208 46. The method of claim 40 wherein said beneficial weighting matrix is
209 obtained from a matrix containing values representing characteristics of said channel, said
210 channel coupling one or more channel inputs and said plurality of channel outputs.

211
212 47. The method of claim 46 wherein said beneficial weighting matrix is
213 obtained by an MMSE procedure.

214

215 48. The method of claim 35 further comprising the step of after said b) step
216 applying a decoding procedure to said symbols.

217
218 49. The method of claim 48 wherein said decoding procedure is applied
219 independently for each of said plurality of subchannels.

220
221 50. The method of claim 48 wherein said decoding procedure is applied
222 independently for each group of subchannels corresponding to an output bin of said
223 substantially orthogonalizing procedure.

224
225 51. The method of claim 48 wherein said decoding procedure is applied
226 independently for each group of subchannels corresponding to a spatial direction.

227
228 52. The method of claim 48 wherein said decoding procedure is applied
229 integrally across all of said plurality of subchannels.

230
231 53. The method of claim 48 wherein said decoding procedure belongs to a
232 group consisting of: Reed-Solomon decoding, CRC decoding, block decoding, and de-
233 interleaving.

234
235 54. The method of claim 48 wherein said decoding procedure comprises a
236 code sequence detection procedure to decode a trellis code, or convolutional code.

237
238 55. The method of claim 54 wherein said code sequence detection procedure
239 employs a metric belonging to a group consisting of: Euclidean metric, weighted Euclidean
240 metric, and Hamming metric.

241
242 56. The method of claim 48 wherein said decoding procedure reduces
243 deleterious effects of interference from undesired transmitters.

244
245 57. The method of claim 35 further comprising the step of:

246 sending a retransmission request when received symbols are
247 determined to include errors.

248
249 58. The method of claim 35 wherein said channel comprises a wireless
250 channel and said plurality of channel outputs are coupled to a plurality of corresponding
251 receiver antenna elements.

252
253 59. The method of claim 35 wherein said plurality of receiver antenna
254 elements are co-located.

255
256 60. The method of claim 35 wherein said plurality of receiver antenna
257 elements are at disparate locations.

258
259 61. In a digital communication system, a method for preparing a sequence of
260 symbols for transmission via a plurality of inputs to a channel, said method comprising the
261 steps of:

262 selecting a weighting vector for optimal transmission;
263 applying a transmitter substantially orthogonalizing procedure to
264 said sequence of symbols to develop a time domain symbol sequence; and
265 multiplying at least one symbol of said time domain symbol
266 sequence by said weighting vector to develop a result vector, elements of said result vector
267 corresponding to symbols to be transmitted via individual ones of said plurality of channel
268 inputs.

269
270 62. The method of claim 61 wherein said weighting vector comprises an
271 element indicating delay to be applied for a particular one of said plurality of channel inputs.

272
273 63. The method of claim 61 wherein said weighting vector is optimized to
274 reduce interference to unintended receivers.

275

276 64. The method of claim 61 wherein said weighting vector is chosen based
277 upon characterization of a desired signal subspace.

278
279 65. The method of claim 64 wherein said weighting vector is chosen further
280 based upon characterization of an undesired signal subspace.

281
282 66. The method of claim 65 wherein said characterizations of said desired
283 signal subspace and said undesired signal subspace are averaged over at least one of time and
284 frequency.

285
286 67. The method of claim 61 wherein said channel comprises a wireless
287 channel and said plurality of channel inputs are associated with a plurality of transmitter
288 antenna elements.

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291

292 68. In a digital communication system, a method for processing a plurality
293 of symbols received via a plurality of outputs of a channel, said method comprising the steps
294 of:

295 selecting a weighting vector for optimal reception;
296 multiplying an input vector whose elements correspond to
297 symbols received substantially simultaneously via a selected one of said plurality of channel
298 outputs by said weighting vector to obtain a time domain symbol corresponding to a particular
299 input bin of a receiver substantially orthogonalizing procedure;
300 repeating said multiplying step for successive received symbols to
301 obtain time domain symbols corresponding to successive input bins of said receiver
302 substantially orthogonalizing procedure; and
303 applying said receiver substantially orthogonalizing procedure to
304 said obtained time domain symbols.

305
306 69. The method of claim 68 wherein said weighting vector comprises an
307 element indicating delay to be applied for a particular one of said plurality of channel outputs.

308
309 70. The method of claim 68 wherein said weighting vector is optimized to
310 reduce deleterious effects of interference from unintended transmitters.

311
312 71. The method of claim 68 wherein said weighting vector is chosen based
313 upon characterization of a desired signal subspace.

314
315 72. The method of claim 71 wherein said weighting vector is chosen further
316 based upon characterization of an undesired signal subspace.

317
318 73. The method of claim 72 wherein said characterizations of said desired
319 signal subspace and said undesired signal subspace are averaged over at least one of frequency
320 and time.
321

322 74. The method of claim 71 wherein said channel comprises a wireless
323 channel and said plurality of channel outputs are associated with a plurality of corresponding
324 receiver antenna elements.

325
326 75. In a digital communication system, a method of preparing symbols for
327 transmission via a plurality of inputs of a channel, said method comprising the steps of:
328 directing symbols to input bins of a transmitter substantially
329 orthogonalizing procedure so that each input bin has an allocated symbol;
330 for each particular input bin, spatially processing said symbol
331 allocated to said particular input bin to develop a spatially processed symbol vector, each
332 element of said spatially processed symbol vector being assigned to one of said channel
333 inputs;
334 applying said transmitter substantially orthogonalizing procedure
335 for a particular channel input, inputs to said substantially orthogonalizing procedure being for
336 each input bin, a symbol of said processed symbol vector for said input bin corresponding to
337 said particular channel input; and
338 repeating said applying step for each of said plurality of channel
339 inputs.

340
341 76. The method of claim 75 further comprising the step of:
342 applying a cyclic prefix processing procedure to outputs of said
343 substantially orthogonalizing procedure independently for each particular channel input.

344
345 77. The method of claim 75 wherein said transmitter substantially
346 orthogonalizing procedure is optimized to reduce interference to unintended receivers.

347
348 78. The method of claim 75 wherein said processing step comprises:
349 multiplying said symbol allocated to said particular input bin by a
350 beneficial weighting vector to obtain said spatially processed symbol vector.

351

79. The method of claim 78 wherein said beneficial weighting vector is an input singular vector of a matrix storing values indicative of said channel, said channel coupling said plurality of channel inputs and one or more channel outputs.

80. The method of claim 78 wherein said beneficial weighting vector is chosen to select a beneficial spatial direction for transmission.

81. The method of claim 80 wherein said beneficial weighting vector is chosen to reduce interference to unintended receivers.

82. The method of claim 81 wherein said beneficial weighting vector is chosen based upon characterization of a desired signal subspace

83. The method of claim 82 wherein said beneficial weighting vector is chosen further based upon characterization of an undesired signal subspace.

84. The method of claim 83 wherein said characterizations of said desired signal subspace and said undesired signal subspace are averaged over at least one of time and frequency.

85. The method of claim 75 wherein said channel comprises a wireless channel and said plurality of channel inputs are associated with a corresponding plurality of transmitter antenna elements.

86. In a digital communication system, a method for processing symbols received by a plurality of outputs of a channel comprising the step of:
applying a receiver substantially orthogonalizing procedure to symbols received via a particular one of said channel outputs;
repeating said applying step for each of said channel outputs to develop a result vector for each of a plurality of output bins of said receiver substantially orthogonalizing procedure, said result vector including a result symbol for each of said channel outputs; and

for each particular output bin of said receiver substantially orthogonalizing procedure, spatially processing said result vector for said particular output bin to develop a spatially processed result symbol for said particular output bin.

87. The method of claim 86 further comprising the step of:
prior to said applying step, applying a cyclic prefix removal procedure to symbols independently for each of said channel outputs.

88. The method of claim 86 wherein said substantially orthogonalizing procedure is optimized to reduce deleterious effects of interference from unintended transmitters.

89. The method of claim 86 wherein said spatially processing step comprises multiplying a beneficial weighting vector by said result vector to obtain said spatially processed result symbol.

90. The method of claim 88 wherein said beneficial weighting vector is an input singular vector of a matrix storing values indicative of characteristics of said channel, said channel coupling one or more channel inputs and said plurality of channel outputs.

91. The method of claim 88 wherein said beneficial weighting vector is chosen to select a particular spatial direction for reception.

92. The method of claim 91 wherein said beneficial weighting vector is chosen to minimize deleterious effects of interference from unintended transmitters.

93. The method of claim 91 wherein said beneficial weighting vector is chosen based upon characterization of a desired signal subspace.

94. The method of claim 93 wherein said beneficial weighting vector is chosen based upon characterization of an undesired signal subspace.

95. The method of claim 94 wherein said characterizations of said desired signal subspace and said undesired signal subspace are averaged over at least one of time and frequency.

96. The method of claim 86 wherein said channel comprises a wireless channel and said plurality of channel outputs are associated with a corresponding plurality of channel outputs.

97. In a digital communication system including a communication channel having one or more inputs and at least one or more outputs, a method for determining characteristics of said channel based on signals received by said one or more outputs, comprising the steps of:

a) receiving via said one or more channel outputs, at least ν training symbols transmitted via a particular spatial direction of said channel, ν being an extent in symbol periods of a duration of significant terms of an impulse response of a channel; and

b) applying a substantially orthogonalizing procedure to said received at least ν training symbols to obtain a time domain response for said spatial direction; and

c) applying an inverse of said substantially orthogonalizing procedure to a zero-padded version of said time domain response to obtain a frequency response for said particular spatial direction.

98. The method of claim 97 wherein said substantially orthogonalizing procedure comprises an inverse Fast Fourier Transform and said inverse of said substantially orthogonalizing procedure comprises a Fast Fourier Transform.

99. The method of claim 98 wherein said a) step comprises receiving exactly ν training symbols.

100. The method of claim 97 further comprising the step of repeating said a), b), c), and d) steps for a plurality of spatial directions.

445
446 101. The method of claim 99 wherein each of said plurality of spatial
447 directions corresponds to transmission through one of said plurality of channel inputs
448 exclusively.

449
450 102. The method of claim 98 wherein said v training symbols belong to a
451 burst of N symbols and said characteristics are determined for said burst.

452
453 103. The method of claim 102 further comprising the steps of repeating said
454 a), b), c), and d) steps for successive bursts.

455
456 104. The method of claim 103 further comprising the step of after, said b)
457 step, smoothing said time-domain response over successive bursts.

458
459 105. The method of claim 104 wherein said smoothing step comprises Kalman
460 filtering.

461
462 106. The method of claim 104 wherein said smoothing step comprises Wiener
463 filtering.

464
465 107. The method of claim 97 wherein said communication channel comprises
466 known and unknown components, wherein said effects of said known components are removed
467 by deconvolution, and characteristics of said unknown components are determined by said a),
468 b), c), and d) steps, thereby reducing .

469
470 108. In a digital communication system including a communication channel
471 having one or more inputs and one or more outputs, a method for determining characteristics
472 of said channel based on signals received via one or more channel outputs, comprising the
473 steps of:

474 receiving training symbols via said channel outputs; and

475 computing characteristics of said channel based on said received
476 training symbols and assumptions that an impulse response of said channel is substantially
477 time-limited and that variation of said impulse response over time is continuous.

478
479 109. In a digital communication system, a method for communicating over a
480 channel having at least one input and at least one output, and having a plurality of either inputs
481 or outputs, said method comprising the steps of:

482 dividing said channel into a plurality of subchannels, each
483 subchannel corresponding to a combination of spatial direction and an input bin of a
484 substantially orthogonalizing procedure; and
485 communicating symbols over one or more of said plurality of
486 subchannels.

487
488 110. In a digital communication system, a method for preparing a sequence of
489 symbols for transmission via a plurality of inputs of a channel, comprising the steps of:

490 a) inputting said symbols of said sequence into a plurality of
491 input corresponding to a plurality of subchannels of said channel, each subchannel
492 corresponding to an input bin of a transmitter substantially orthogonalizing procedure and a
493 channel input; and

494 b) applying, independently for each said channel input, said
495 transmitter substantially orthogonalizing procedure to said symbols assigned to each said
496 channel input.

497
498 111. A method of processing a sequence of symbols received via a plurality of
499 outputs of a channel, said method comprising the steps of:

500 a) applying a substantially orthogonalizing procedure to said
501 sequence of symbols, said procedure being applied independently for each of said plurality of
502 channel outputs, each output symbol of said substantially orthogonalizing procedure
503 corresponding to a subchannel identified by a combination of a particular output bin and a
504 particular one of said channel outputs; and

505 b) processing symbols in said subchannels.

506
507 112. In a digital communication system, apparatus for communicating
508 comprising:
509 a transmitter that transmits signals from one or more transmitter
510 antenna elements;
511 a receiver that receives said signals from via a plurality of
512 receiver antenna elements;
513 wherein separation of radiation patterns among either said
514 transmitter antenna elements or said receiver antenna elements is insufficient to
515 establish completely isolated spatial directions for communication; and wherein
516 at least one of said transmitter and said receiver comprises a
517 processor that processes said signals to increase isolation between spatial directions employed
518 for communication at a common frequency.
519

520 113. The apparatus of claim 112 wherein a channel coupling said plurality of
521 transmitter antenna elements and receiver antenna elements at said common frequency is
522 characterized by a spatial channel matrix having a rank greater than one.
523

524 114. In a digital communication system, apparatus for communicating
525 comprising:
526 a transmitter transmitting signals from one or more transmitter
527 antenna elements;
528 a receiver receiving said signals via a plurality of receiver
529 antenna elements;
530 wherein separation of radiation patterns among either said
531 transmitter antenna elements or said receiver antenna elements is insufficient to
532 establish completely isolated spatial directions for communication; and wherein
533 at least one of said transmitter and said receiver comprises a
534 processor that processes said signals to increase isolation between subchannels, each
535 subchannel associated with a spatial direction and a bin of a substantially orthogonalizing
536 procedure.

537
538 115. The apparatus of claim 114 wherein said substantially orthogonalizing
539 procedure belongs to a group including: an inverse Fast Fourier Transform, a Fast Fourier
540 Transform, a Hilbert transform, a wavelet transform, and processing through a set of bandpass
541 filter/frequency upconverter pairs operating at spaced apart frequencies..

542
543 116. In a digital communication system, apparatus for preparing a sequence of
544 symbols for transmission via a plurality of inputs of a channel:

545 a plurality of parallel subchannel inputs receiving said symbols, said parallel
546 subchannel inputs corresponding to a plurality of subchannels, each subchannel corresponding
547 to an input bin of a transmitter substantially orthogonalizing procedure and a spatial direction;
548 a spatial processor that, for each input bin, spatially processor symbols received
549 by said subchannel inputs corresponding to said input bin, to develop a spatially processed
550 symbol to assign to each combination of channel input and input bin of said transmitter
551 substantially orthogonalizing procedure; and

552 a substantially orthogonal procedure processor system that applies,
553 independently for each said channel input, said transmitter substantially orthogonalizing
554 procedure to said spatially processed symbols assigned to each said channel input.

555
556 117. The apparatus of claim 116 wherein said spatial processor has the effect
557 of making spatial directions of said subchannels into a set of orthogonal spatial dimensions.

558
559 118. The apparatus of claim 116 wherein said transmitter substantially
560 orthogonalizing procedure belongs to one of a group consisting of an inverse Fast Fourier
561 Transform, a Fast Fourier Transform, a discrete cosine transform, a Hilbert transform, a
562 wavelet transform, and processing through a plurality of bandpass filter/frequency converter
563 pairs centered at spaced apart frequencies.

564
565 119. The apparatus of claim 116 further comprising: a cyclic prefix processor
566 that applies a cyclic prefix processing procedure to a result of said substantially
567 orthogonalizing procedure independently for each channel input.

568
569 120. The apparatus of claim 116 wherein said transmitter substantially
570 orthogonalizing procedure is optimized to reduce interference to unintended receivers.
571

572 121. The apparatus of claim 116 wherein said spatial processor comprises, for
573 each particular input bin, a weight multiplier that multiplies a vector comprising symbols
574 allocated to subchannels corresponding to said input bin by a beneficial weighting matrix,
575 elements of a result vector of said weight multiplier corresponding to different channel inputs
576 of said plurality of channel inputs.
577

578 122. The apparatus of claim 121 wherein said beneficial weighting matrix
579 comprises an input singular matrix of a matrix containing values representing characteristics of
580 said channel, said channel coupling said plurality of channel inputs to one or more channel
581 outputs.
582

583 123. The apparatus of claim 121 wherein said beneficial weighting matrix is
584 obtained from a matrix containing values representing characteristics of a channel coupling
585 said plurality of channel inputs to one or more channel outputs.
586

587 124. The apparatus of claim 121 wherein said beneficial weighting matrix is
588 chosen to reduce interference to unintended receivers.
589

590 125. The apparatus of claim 124 wherein said beneficial weighting matrix is
591 chosen based upon characterization of a desired signal subspace.
592

593 126. The apparatus of claim 125 wherein said beneficial weighting matrix is
594 chosen further based upon characterization of an undesired signal subspace.
595

596 127. The apparatus of claim 126 wherein characterizations of said desired
597 signal subspace and said undesired signal subspace are averaged over at least one of time and
598 frequency.

128. The apparatus of claim 116 wherein said spatial processor operates so as to reduce interference radiated to unintended receivers.

129. The apparatus of claim 116 wherein said spatial processor, allocates symbols to each combination of channel input and input bin so that there is a one-to-one mapping between spatial direction of a particular subchannel to which a particular symbol has been allocated and channel input to which said particular symbol is allocated.

130. The apparatus of claim 116 further comprising a coder that applies a coding procedure to said symbols prior to processing by said spatial processor.

131. The apparatus of claim 130 wherein said coding procedure is applied independently for each of said subchannels.

132. The apparatus of claim 130 wherein said coding procedure is applied independently for each group of subchannels corresponding to an input bin of said substantially orthogonalizing procedure.

133. The apparatus of claim 130 wherein said coding procedure is applied independently for each group of subchannels corresponding to a particular spatial direction.

134. The apparatus of claim 130 wherein said coding procedure is applied integrally across all of said subchannels.

135. The apparatus of claim 130 wherein said coding procedure belongs to a group consisting of: convolutional coding, Reed-Solomon coding, CRC coding, block coding, trellis coding, turbo coding, and interleaving.

136. The apparatus of claim 130 wherein said coding procedure comprises a trellis coding procedure.

630
631 137. The apparatus of claim 136 wherein a code design of said trellis coding
632 procedure is based on one of: improved bit error performance in interference channels, a
633 periodic product distance metric, exhaustive code polynomial search for favorable bit error
634 rate polynomial searches, combined weighting of product distance and Euclidean distance,
635 product distance of multiple Euclidean distances over short code segments or over a multi-
636 dimensional symbol, and sum of product distances over short code segments.

637
638 138. The apparatus of claim 136 wherein a code design of said trellis coding
639 procedure is optimized for performance in a fading matrix channel.

640
641 139. The apparatus of claim 130 wherein said coding procedure comprises a
642 one-dimensional trellis coding procedure followed by an interleaving procedure with sequential
643 groups of symbols output by said trellis coding having their internal order maintained by said
644 interleaving procedure.

645
646 140. The apparatus of claim 130 wherein said coding procedure comprises a
647 multi-dimensional trellis coding procedure followed by an interleaving procedure with groups
648 of one-dimensional symbols output simultaneously by said multi-dimensional trellis coding
649 procedure having their internal order maintained by said interleaving procedure.

650
651 141. The apparatus of claim 130 wherein bit loading and power are allocated
652 to each subchannel.

653
654 142. The apparatus of claim 116 further comprising an ARQ system that
655 retransmits symbols via at least one of said spatial processor, and said substantially
656 orthogonalizing procedure processor upon receipt of a notification that said symbols to be
657 retransmitted have been incorrectly received.
658

143. The apparatus of claim 116 wherein said channel comprises a wireless channel and said plurality of channel inputs are associated with a corresponding plurality of transmitter antenna elements

144. The apparatus of claim 142 wherein said plurality of transmitter antenna elements are co-located.

145. The apparatus of claim 144 wherein said plurality of transmitters are at disparate locations.

146. Apparatus of processing a sequence of symbols received via a plurality of outputs of a channel, said apparatus comprising:

a substantially orthogonalizing procedure processor system that applies a receiver substantially orthogonalizing procedure to said sequence of symbols, said procedure being applied independently for each of said plurality of channel outputs, each output symbol of said substantially orthogonalizing procedure corresponding to a particular output bin and a particular one of said channel outputs; and

a spatial processor that, for each output bin, spatially processes symbols corresponding to said output bin to develop spatially processed symbols assigned to a plurality of spatial directions, each combination of spatial direction and output bin specifying one of a plurality of subchannels.

147. The apparatus of claim 146 wherein said spatial processor operates to make said plurality of spatial directions into a set of orthogonal spatial dimensions.

148. The apparatus of claim 146 wherein said receiver substantially orthogonalizing procedure belongs to one of a group consisting of an inverse Fast Fourier Transform, a Fast Fourier Transform, a discrete cosine transform, a Hilbert transform, a wavelet transform, and processing through a plurality of bandpass filter/frequency converter pairs centered at spaced apart frequencies.

149. The apparatus of claim 146 further comprising: a cyclic prefix processor that applies a cyclic prefix removal procedure to said sequence of symbols independently for each of said channel outputs.

150. The apparatus of claim 146 wherein said receiver substantially orthogonalizing procedure is optimized to reduce deleterious effects of interference from undesired co-channel transmitters.

151. The apparatus of claim 146 wherein said spatial processor comprises, for each particular output bin, a weight multiplier that multiplies a vector comprising symbols of said output bin by a beneficial weighting matrix, elements of a result vector of said multiplier corresponding to different spatial directions.

152. The apparatus of claim 151 wherein said beneficial weighting matrix comprises an output singular vector of a matrix containing values representing characteristics of said channel, said channel coupling one or more channel inputs to said plurality of channel outputs.

153. The apparatus of claim 151 wherein said beneficial weighting matrix is chosen to minimize deleterious effects of interference from undesired transmitters.

154. The apparatus of claim 151 wherein said beneficial weighting matrix is chosen based upon characterization of a desired signal subspace.

155. The apparatus of claim 154 wherein said beneficial weighting matrix is chosen further based upon characterization of an undesired signal subspace.

156. The apparatus of claim 155 wherein said characterizations of said desired signal subspace and said undesired signal subspace are averaged over at least one of time and frequency.

157. The apparatus of claim 151 wherein said beneficial weighting matrix is obtained from a matrix containing values representing characteristics of said channel, said channel coupling one or more channel inputs and said plurality of channel outputs.

158. The apparatus of claim 157 wherein said beneficial weighting matrix is obtained by an MMSE procedure.

159. The apparatus of claim 146 further comprising: a decoder that applies a decoding procedure to said spatially processed symbols.

160. The apparatus of claim 159 wherein said decoding procedure is applied independently for each of said plurality of subchannels.

161. The apparatus of claim 159 wherein said decoding procedure is applied independently for each group of subchannels corresponding to an output bin of said substantially orthogonalizing procedure.

162. The apparatus of claim 159 wherein said decoding procedure is applied independently for each group of subchannels corresponding to a spatial direction.

163. The apparatus of claim 159 wherein said decoding procedure is applied integrally across all of said plurality of subchannels.

164. The apparatus of claim 159 wherein said decoding procedure belongs to a group consisting of: Reed-Solomon decoding, CRC decoding, block decoding, and de-interleaving.

165. The apparatus of claim 159 wherein said decoding procedure comprises a code sequence detection procedure to decode a trellis code, or convolutional code.

166. The apparatus of claim 165 wherein said code sequence detection procedure employs a metric belonging to a group consisting of: Euclidean metric, weighted Euclidean metric, and Hamming metric.

167. The apparatus of claim 159 wherein said decoding procedure reduces deleterious effects of interference from undesired transmitters.

168. The apparatus of claim 146 further comprising:
a system that sends a retransmission request when received symbols are determined to include errors.

169. The apparatus of claim 170 wherein said channel comprises a wireless channel and said plurality of channel outputs are coupled to a plurality of corresponding receiver antenna elements.

171. The apparatus of claim 170 wherein said plurality of receiver antenna elements are co-located.

172. The apparatus of claim 170 wherein said plurality of receiver antenna elements are at disparate locations.

173. In a digital communication system, apparatus for preparing a sequence of symbols for transmission via a plurality of inputs to a channel, said apparatus comprising:

a substantially orthogonal procedure processor that applies a transmitter substantially orthogonalizing procedure to said sequence of symbols to develop a time domain symbol sequence; and

a weight multiplier that multiplies at least one symbol of said time domain symbol sequence by a weighting vector selected for improved communication to develop a result vector, elements of said result vector corresponding to symbols to be transmitted via individual ones of said plurality of channel inputs.

174. The apparatus of claim 173 wherein said weighting vector comprises an element indicating delay to be applied for a particular one of said plurality of channel inputs.

175. The apparatus of claim 174 wherein said weighting vector is optimized to reduce interference to unintended receivers.

176. The apparatus of claim 173 wherein said weighting vector is chosen based upon characterization of a desired signal subspace.

177. The apparatus of claim 176 wherein said weighting vector is chosen further based upon characterization of an undesired signal subspace.

178. The apparatus of claim 177 wherein said characterizations of said desired signal subspace and said undesired signal subspace are averaged over at least one of time and frequency.

179. The apparatus of claim 173 wherein said channel comprises a wireless channel and said plurality of channel inputs are associated with a plurality of transmitter antenna elements.

180.

180. In a digital communication system, apparatus for processing a plurality of symbols received via a plurality of outputs of a channel, said apparatus comprising:
a weight multiplier that performs a multiplication of an input vector whose elements correspond to symbols received substantially simultaneously via a selected one of said plurality of channel outputs by a weighting vector to obtain a time domain symbol corresponding to a particular input bin of a receiver substantially orthogonalizing procedure and that repeats said multiplication for successive received symbols to obtain time domain symbols corresponding to successive input bins of said receiver substantially orthogonalizing procedure; and

a substantial orthogonalizing procedure processor that applies said substantially orthogonalizing procedure processor to said obtained time domain symbols.

813
814 181. The apparatus of claim 180 wherein said weighting vector comprises an
815 element indicating delay to be applied for a particular one of said plurality of channel outputs.
816

817 182. The apparatus of claim 180 wherein said weighting vector is optimized
818 to reduce deleterious effects of interference from unintended transmitters.
819

820 183. The apparatus of claim 180 wherein said weighting vector is chosen
821 based upon characterization of a desired signal subspace.
822

823 184. The apparatus of claim 183 wherein said weighting vector is chosen
824 further based upon characterization of an undesired signal subspace.
825

826 185. The apparatus of claim 184 wherein said characterizations of said desired
827 signal subspace and said undesired signal subspace are averaged over at least one of frequency
828 and time.
829

830 186. The apparatus of claim 180 wherein said channel comprises a wireless
831 channel and said plurality of channel outputs are associated with a plurality of corresponding
832 receiver antenna elements.
833

834 187. In a digital communication system, apparatus for preparing symbols for
835 transmission via a plurality of inputs of a channel, said apparatus comprising:

836 a plurality of symbol inputs, each of said symbol inputs receiving a symbol
837 intended for a particular input bin of a transmitter substantially orthogonalizing procedure so
838 that each of a plurality of input bins of said transmitter substantially orthongonalizing
839 procedure has an allocated symbol;

840 a spatial processor that, for each particular input bin of said plurality of input
841 bins, spatially processes said symbol allocated to said particular input bin to develop a spatially
842 processed symbol vector, each element of said spatially processed symbol vector being
843 assigned to one of said channel inputs; and

a substantially orthogonalizing procedure processor that applies said substantially orthogonalizing procedure for a particular channel input, inputs to said substantially orthogonalizing procedure being for each input bin, a symbol of said processed symbol vector for said input bin corresponding to said particular channel input, and that applies said substantially orthogonalizing procedure for each of said plurality of channel inputs.

188. The apparatus of claim 187 further comprising:
a cyclic prefix processor that applies a cyclic prefix processing procedure to outputs of said substantially orthogonalizing procedure independently for each particular channel input.

189. The apparatus of claim 187 wherein said substantially orthogonalizing procedure is optimized to reduce interference to unintended receivers.

190. The apparatus of claim 187 wherein said spatial processor comprises:
a weight multiplier that multiplies said symbol allocated to said particular input bin by a beneficial weighting vector to obtain said spatially processed symbol vector.

191. The apparatus of claim 190 wherein said beneficial weighting vector is an input singular vector of a matrix storing values indicative of characteristics of said channel, said channel coupling said plurality of channel inputs and one or more channel outputs.

192. The apparatus of claim 190 wherein said beneficial weighting vector is chosen to select a beneficial spatial direction for transmission.

193. The apparatus of claim 191 wherein said beneficial weighting vector is chosen to reduce interference to unintended receivers.

194. The apparatus of claim 193 wherein said beneficial weighting vector is chosen based upon characterization of a desired signal subspace

875 195. The apparatus of claim 194 wherein said beneficial weighting vector is
876 chosen further based upon characterization of an undesired signal subspace.
877

878 196. The apparatus of claim 195 wherein said characterizations of said desired
879 signal subspace and said undesired signal subspace are averaged over at least one of time and
880 frequency.
881

882 197. The apparatus of claim 187 wherein said channel comprises a wireless
883 channel and said plurality of channel inputs are associated with a corresponding plurality of
884 transmitter antenna elements.
885

886 198. In a digital communication system, apparatus for processing symbols
887 received by a plurality of outputs of a channel comprising:

888 a substantially orthogonalizing procedure processor that applies a receiver
889 substantially orthogonalizing procedure to symbols received via a particular one of said
890 channel outputs and that said applies said receiver substantially orthogonalizing procedure for
891 each of said channel outputs to develop a result vector for each of a plurality of output bins of
892 said substantially orthogonalizing procedure, said result vector including a result symbol for
893 each of said channel outputs; and

894 a spatial processor that, for each particular output bin of said substantially
895 orthogonalizing procedure, spatially processes said result vector for said particular output bin
896 to develop a spatially processed result symbol for said particular output bin.
897

898 199. The apparatus of claim 198 further comprising: a cyclic prefix removal
899 processor that applies a cyclic prefix removal procedure to symbols independently for each of
900 said channel outputs.
901

902 200. The apparatus of claim 198 wherein said substantially orthogonalizing
903 procedure is optimized to reduce deleterious effects of interference from unintended
904 transmitters.
905

201. The apparatus of claim 198 wherein said spatially processor comprises a weight multiplier that multiplies a beneficial weighting vector by said result vector to obtain said spatially processed result symbol.

202. The apparatus of claim 201 wherein said beneficial weighting vector is an input singular vector of a matrix storing values indicative of characteristics of said channel, said channel coupling one or more channel inputs and said plurality of channel outputs.

203. The apparatus of claim 201 wherein said beneficial weighting vector is chosen to select a particular spatial direction for reception.

204. The apparatus of claim 203 wherein said beneficial weighting vector is chosen to minimize deleterious effects of interference from unintended transmitters.

205. The apparatus of claim 204 wherein said beneficial weighting vector is chosen based upon characterization of a desired signal subspace.

206. The apparatus of claim 205 wherein said beneficial weighting vector is chosen based upon characterization of an undesired signal subspace.

207. The apparatus of claim 206 wherein said characterizations of said desired signal subspace and said undesired signal subspace are averaged over at least one of time and frequency.

208. The apparatus of claim 198 wherein said channel comprises a wireless channel and said plurality of channel outputs are associated with a corresponding plurality of channel outputs.

209. In a digital communication system including a communication channel having one or more inputs and at least one or more outputs apparatus for determining

characteristics of said channel based on signals received by said one or more outputs, comprising:

a receiver system receiving via said one or more channel outputs, at least training symbols transmitted via a particular spatial direction of said channel, being an extent in symbol periods of a duration of significant terms of an impulse response of a channel;

a substantially orthogonalizing procedure processor that applies a substantially orthogonalizing procedure processor to said received at least training symbols to obtain a time domain response for said particular spatial direction; and

an inverse substantially orthogonalizing procedure processor that applies an inverse of said substantially orthogonalizing procedure to a zero-padded version of said time domain response to obtain a frequency response for said particular spatial direction.

210. The apparatus of claim 209 wherein said substantially orthogonalizing procedure comprises an inverse Fast Fourier Transform and said inverse of said substantially orthogonalizing procedure comprises a Fast Fourier Transform.

211. The apparatus of claim 209 wherein said receiver system receives exactly training symbols.

212. The apparatus of claim 209 wherein said receiver system, said substantially orthogonalizing procedure processor and said inverse substantially orthogonalizing procedure process operate repeatedly for a plurality of spatial directions.

213. The apparatus of claim 209 wherein each of said plurality of spatial directions corresponds to transmission through one of said plurality of channel inputs exclusively.

214. The apparatus of claim 209 wherein said training symbols belong to a burst of N symbols and said characteristics are determined for said burst.

966 215. The apparatus of claim 214 said receiver system, said substantially
967 orthogonalizing procedure processor and said inverse substantially orthogonalizing procedure
968 process operate repeatedly for a plurality of bursts.

969
970 216. The apparatus of claim 215 further comprising:
971 means for smoothing said time-domain response over successive bursts.

972
973 217. The apparatus of claim 216 wherein said smoothing means comprises:
974 means for Kalman filtering said time-domain response over successive bursts.

975
976 218. The apparatus of claim 217 wherein said smoothing means comprises
977 means for Wiener filtering said time-domain response over successive bursts.

978
979 219. The apparatus of claim 209 wherein said communication channel
980 comprises known and unknown components, wherein said effects of said known components
981 are removed by deconvolution, and characteristics of said unknown components are
982 determined by said a), b), c), and d) steps, thereby reducing .

983
984 220. In a digital communication system including a communication channel
985 having one or more inputs and one or more outputs, apparatus for determining characteristics
986 of said channel based on signals received via one or more channel outputs, comprising:
987 a receiver that receives training symbols via said channel outputs; and
988 a processor that computes characteristics of said channel based on said received
989 training symbols and assumptions that an impulse response of said channel is substantially
990 time-limited and that variation of said impulse response over time is continuous.

991
992 221. In a digital communication system, apparatus for communicating over a
993 channel having at least one input and at least one output, and having a plurality of either inputs
994 or outputs, said apparatus comprising:

995 means for dividing said channel into a plurality of subchannels, each subchannel
996 corresponding to a combination of spatial direction and an input bin of a substantially
997 orthogonalizing procedure; and

998 means for communicating symbols over one or more of said plurality of
999 subchannels.

1000

1001 222. In a digital communication system, apparatus for preparing a sequence of
1002 symbols for transmission via a plurality of inputs of a channel, said apparatus comprising:

1003 a plurality of parallel subchannel inputs that receive said sequence of symbols,
1004 said subchannel inputs corresponding to a plurality of subchannels, each subchannel
1005 corresponding to an input bin of a transmitter substantially orthogonalizing procedure and a
1006 channel input; and

1007 a substantially orthogonalizing procedure processor that applies, independently
1008 for each said channel input, said transmitter substantially orthogonalizing procedure to said
1009 symbols assigned to each said channel input.

1010

1011 223. Apparatus for processing a sequence of symbols received via a plurality
1012 of outputs of a channel, said apparatus comprising the steps of:

1013 a substantially orthogonalizing procedure processor that applies a receiver
1014 substantially orthogonalizing procedure to said sequence of symbols, said procedure being
1015 applied independently for each of said plurality of channel outputs, each output symbol of said
1016 receiver substantially orthogonalizing procedure corresponding to a subchannel identified by a
1017 combination of a particular output bin and a particular one of said channel outputs; and

1018 a processor that processes symbols in said subchannels.

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